Three Dimensional Displacement and Function of the Right Ventricle Using Optical Flow with Tagged Magnetic Resonance Imaging

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Abstract

A new technique to analyse the whole 3D motion and the local function of the right ventricle is presented.

Using magnetic resonance images tagged with complementary spatial modulation of magnetization (CSPAMM), the displacement field is calculated using a 2D multi-scale optical flow algorithm applied on short-axis and radial long-axis slices. Coordinates and displacement over time of points on these orientations are computed, so that a finite element model can be built. This resulting 3D reconstruction illustrates full right ventricle motion.

Ten healthy hearts have been reconstructed, and the resulting 3D view allowed visualisation of the whole systole and the beginning of the wave of diastolic release from base to apex. These results could serve as a basis for further studies on various pathologic right ventricle conditions.

1. Introduction

Right ventricle (RV) contraction and its alteration haven't yet been fully investigated, because of difficulties encountered due to wall thinness. However, abnormal RV motion is of interest in various pathologies such as ischemia, dysplasia, hypertrophy or chronic obstructive pulmonary disease.

Magnetic Resonance Imaging (MRI) is a powerful mean for studying human body. SPAMM (Spatial Modulation of Magnetisation) MR tagging is a useful non-invasive method for visualization and quantification of tissue motion. Tags from regular patterns are placed within the tissues in the first image, such that any motion of the tissue causes a tag deformation. This technique gives additional information about motion throughout the myocardium. In this paper, we describe an approach based on optical flow method to analyse the RV 3D motion using 2D tagged MRI data.

Optical flow is a method to estimate displacement field between two images. This paper follows the approach of Horn & Schunck, in which the aim is to minimize a global energy that includes a luminosity conservation constraint and a smoothness constraint. The assumption that brightness remains constant in time cannot be easily applied with the SPAMM tagging method, since tag pattern fade away in time.

Another tissue tagging method called CSPAMM (Complementary Spatial Modulation of Magnetisation) permits to avoid such a problem. This technique is based on two complementary SPAMM sequences.

Minimizing the optical flow global energy function is a complex problem, because of possible local minima and the large number of possible label configurations. To regularize this problem, we developed a method similar to that described by Perez and Heitz, in which the search of the minimum energy configuration is performed using a deterministic multi-scale descent optimization algorithm.

The optical flow algorithm is applied on several orthogonal orientations. Displacement fields of each slice are combined in order to estimate the RV 3D motion.

Section II is the description of methods for image acquisition and image motion estimation. Section III presents our results, which are discussed in section IV.

2. Methods

2.1. Image acquisition

The CSPAMM [1] tagging MR is a useful technique to capture motion of the ventricular walls. It needs two complementary SPAMM sequences: the first acquired with +90°; +90° RF pulses, and the second acquired with +90°; -90° RF pulses. The subtraction of the two resulting images permits to construct a new image, in which tag patterns do not fade away in time.

Acquisitions were performed on a 1.5T Philips MRI. Ten volunteers, with no personal or familial history of cardiac disease, underwent tagged gated MRI of the right ventricle. CSPAMM preparation with 8 mm tag spacing and a 23 ms temporal resolution was followed by a multi-shot echo-planar acquisition (EPI factor 11). Two tag orientations per slice were acquired during one breath hold: vertical and horizontal. These two orientations have been combined to create a grid aspect. The high contrast between tagged and non tagged tissue permits a best following of the myocardium deformation.

Short axis was used, as well as orthogonal planes with radial orientation around a long axis of the right ventricle. These orientations are represented figure 1.

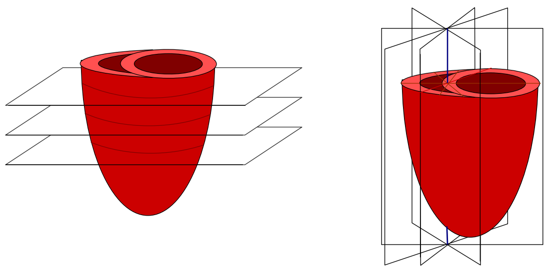

Figure 1. Short-axis orientation and radial long-axis orientation

2.2. Motion estimation

Optical flow algorithm is a differential technique to estimate the displacement of a pixel between two images. It assumes that as points move; their brightness remains constant in time:

$$I(x+dx, y+dy, t+dt) = I(x,y,t) \quad (1)$$

Expanding the left-hand side around the point (x,y,t), and subtracting *I(x,y,t)* from both side, we get:

$$\frac{dx}{dt}\frac{\partial I(x,y,t)}{\partial x} + \frac{dy}{dt}\frac{\partial I(x,y,t)}{\partial y} + \frac{\partial I(x,y,t)}{\partial t} = 0 \quad (2)$$

which leads to the *optical flow equation*:

$$uI_x + vI_y + I_t = 0 \quad (3)$$

where I_x, I_y, I_t are the partial spatial and time brightness derivatives respectively, u and v are the temporal derivative of x and y respectively.

To determine velocity field, we try to estimate u and v. This is an ill-posed problem, and it has to be combined to another constraint to be solved.

Horn & Schunck [2] combined this gradient constraint with a global smoothness term, minimizing

$$\iint \left[(uI_x + vI_y + I_t)^2 + \alpha^2 . \left(\frac{\partial u}{\partial x}^2 + \frac{\partial u}{\partial y}^2 + \frac{\partial v}{\partial x}^2 + \frac{\partial v}{\partial y}^2 \right) \right] dxdy \quad (4)$$

where α is the smoothness coefficient.

To reduce time of convergence and to avoid local minima, Perez and Heitz [3] developed a multiscale descent optimization algorithm. The energy function is minimized with a coarse-to-fine multigrid strategy. In contrast to multiresolution approaches, the multiscale approach uses the finest spatial resolution for all observations and varies the scale of the configuration space, as shown figure 2.

At the first level, a configuration is estimated, so as the displacement field is constant all over the image. At each following level, the grid is partitioned (each block being divided by 4), and the displacement field is re-estimated, but remains constant all over each new block. At the finest configuration level, blocks are of size 1 by 1 pixel. This leads to estimation of the displacement field according to the original resolution.

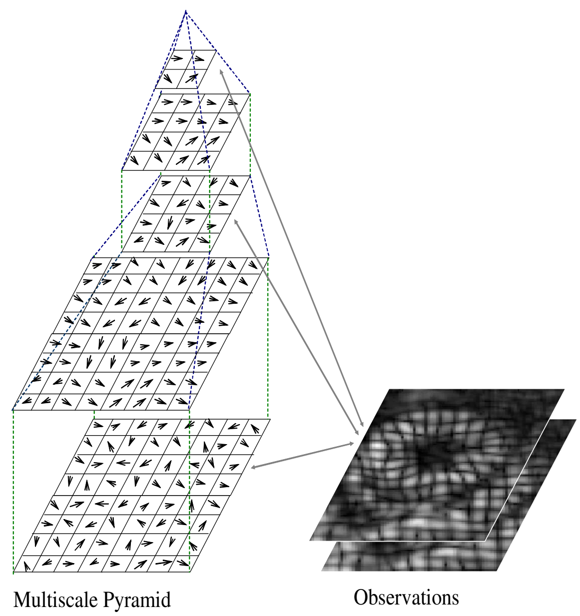

Figure 2. Structure of the multiscale minimization algorithm

This algorithm has to be applied to several slices, in order to obtain information concerning the whole ventricle movement.

3. Results

Optical flow algorithm applied on CSPAMM images allowed us to estimate the displacement field between two images, as shown figure 3. With this result, a fine analysis of the displacement of each point of the RV can be done.

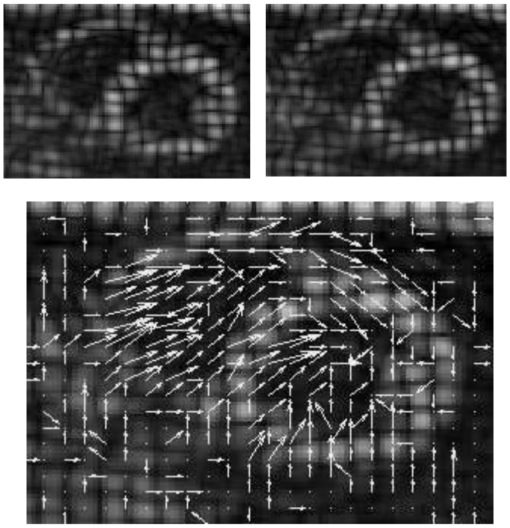

Figure 3. Displacement field estimated between the two upper images

At a given short-axis slice, the approximate contour of the RV has to be determined. Each point of this contour has to be at the junction between the short-axis slice and a radial long-axis slice.

As the displacement has been calculated for each long-axis slice, a simple change of coordinates can provide the vertical displacement of each point of the contour.

By repeating this method at each short-axis slice, a 3D grid is obtained, in which the displacement of each point is known. This permits to obtain a 3D finite element model, as shown figure 4.

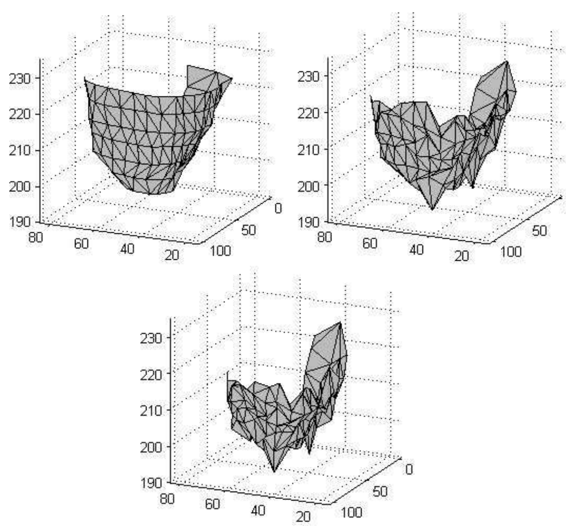

Figure 4. Three dimensional representation of the right ventricle a 3 different stages of the contraction cycle

4. Discussion and conclusions

The 3D movement of the RV reveals some discontinuities in time. The problem is due to the tag profile: points can “jump” from a tag to another. To avoid this problem, a temporal constraint can be introduced in the optical flow algorithm. This constraint would penalize important variations of displacement field, while significantly increasing computation time. A better temporal resolution could also help to correct this problem.

To estimate the 3D displacement, the algorithm uses two different 2D directions. The short-axis slices give the displacement toward two directions (X and Y), and the radial long-axis slices give the displacement toward two other directions, which combined give the displacement toward Z. By using a three-dimensional acquisition [4], a 3D optical flow algorithm could be applied on the data, and the results would be more accurate.

While determining the contour of the RV, a registration problem appears: RV position slightly differs from short axis orientation to radial long-axis orientation. The points of the contour chosen in short-axis do not correspond to RV points in the radial long-axis, and the displacement estimated is not correct. These problems are due to a respiration movement. If the patient does not breathe the same way from an acquisition to another, his heart’s position would differ too. To correct this default, a manually registration has been added to the algorithm. A three-dimensional respiratory-gated acquisition could also avoid this problem.

CSPAMM MR tagging is a powerful mean to evaluate RV displacement. Several slices combination permits to realize a 3D moving model. However, the estimation of RV displacement lacks of precision.

Tagged MRI may benefit of faster and more accurate imagery, especially with spiral Fourier acquisitions. Thus, quality of data used for optical flow algorithm would be better, especially concerning spatial and temporal resolution.

The optical flow algorithm could also be improved, by introducing a temporal smoothness constraint, and by extending it in three dimensions.

Eventually, with a more accurate points following, this method could become a fast and useful tool to help physicians to study right ventricular function.

References

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